



INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

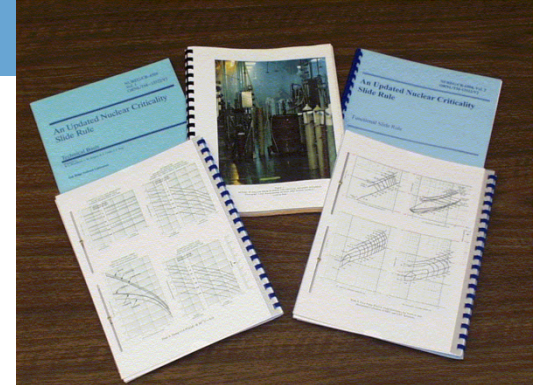
Update of the Nuclear Criticality Slide Rule for Emergency Response to a Nuclear Criticality Accident

Matthieu DULUC, Aurélie BARDELAY, Dave HEINRICHS, Calvin HOPPER,
Richard JONES, Soon KIM, Thomas MILLER and Chris WILSON



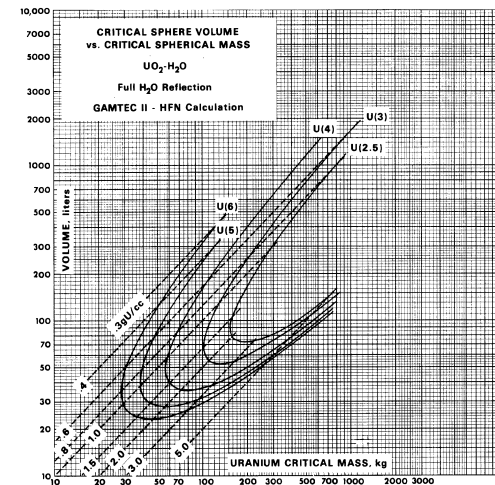
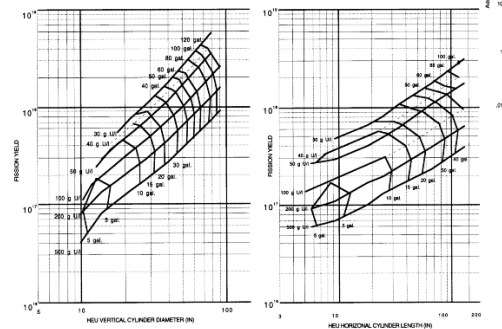
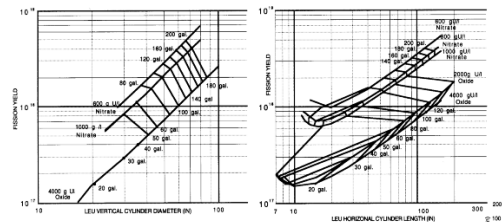
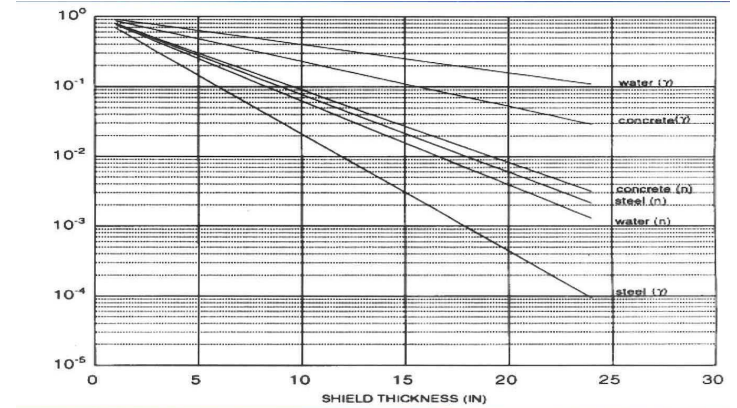
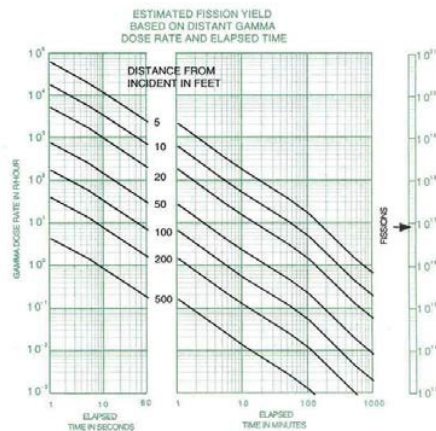
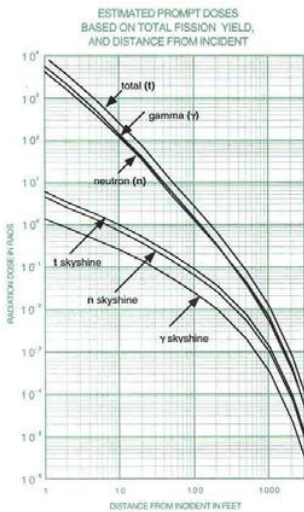
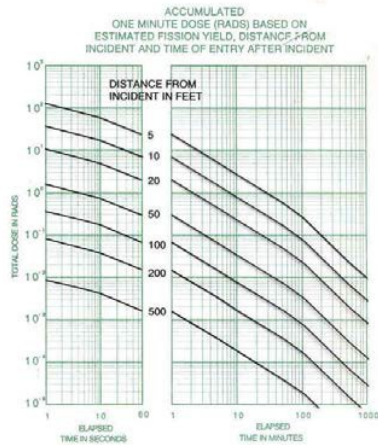
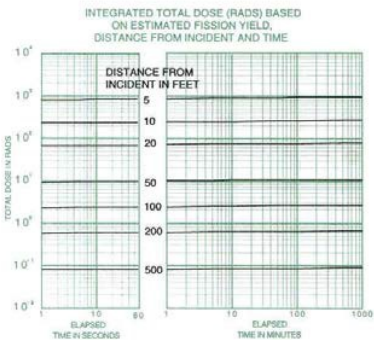
March 15, 2016
Sandia National Laboratory

Slide Rule ?



- April 1997, An Updated Nuclear Criticality Slide Rule
 - ORNL/TM-13322/V1 & V2: Technical Basis / Functional Slide Rule
- This document gives order of magnitude estimates of key parameters, useful for emergency response teams and public authorities:
 - The magnitude of the **number of fissions** based on personnel or field radiation measurements or various critical system parameter inputs,
 - Neutron- and gamma-**dose** at variable unshielded distances from the accident,
 - The **skyshine** component of the dose,
 - Time-integrated radiation **dose** estimates,
 - One-minute **decay-gamma** radiation dose,
 - and **dose-reduction factors** for variable thicknesses of steel, concrete and water.

US Slide Rule



Solution of U(93.2)O₂(NO₃)₂ @ H/²³⁵U = 500

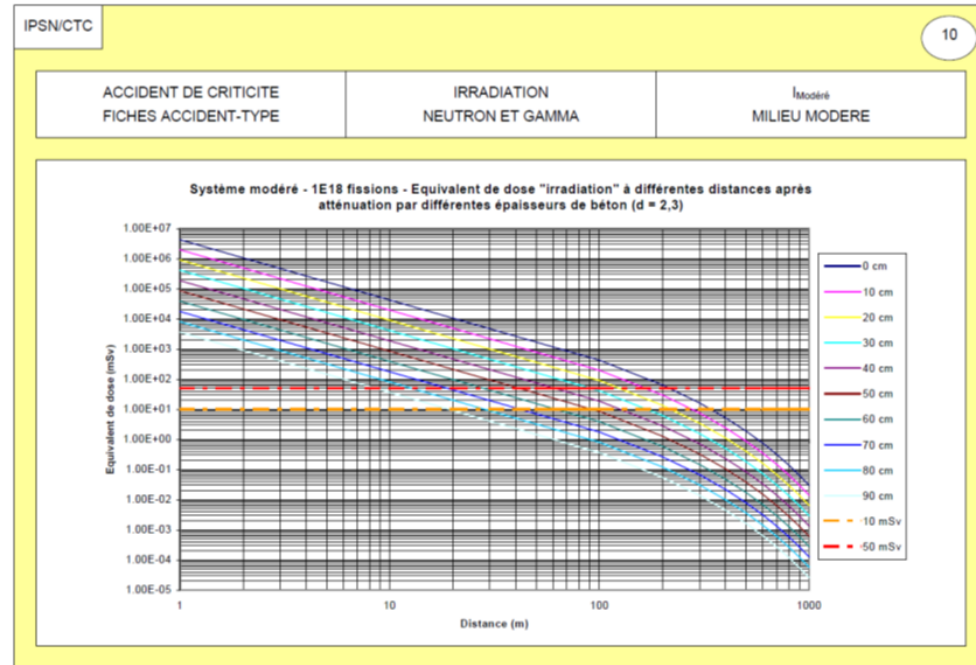
IRSN « Slide Rule »

2000, IPSN « Slide Rule »

- 2 internal reports:
 - Operational document
 - Annexes to operational document

Objectives was to estimate:

- Direct Neutron and gamma doses
- Fission Product release dose (created by the accident)
- Initial fissile material release dose



IPSN/CTC

ACCIDENT DE CRITICITE
FICHES ACCIDENT-TYPE

EXPOSITION AUX
PRODUITS DE FISSIONS FRAIS

FFF

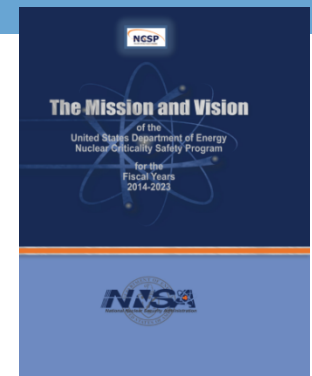
Conséquences radiologiques :

Doses à T+20h (mSv)	DHS			DPS			DHS plus		
	500 m	1 km	2 km	500 m	1 km	2 km	500 m	1 km	2 km
Externe par exposition au parastre (adulte)	GR 4.6E-1	1.4E-1	3.8E-2	1.4E+0	3.9E-1	1.0E-1	4.5E-1	1.4E-1	3.7E-2
Autres	2.1E-2	7.4E-3	2.0E-3	6.9E-2	1.8E-2	4.4E-3	2.4E-2	7.1E-3	1.9E-3
Total	7.5E-1	2.3E-1	6.1E-2	1.5E+0	4.1E-1	1.0E-1	6.9E-1	2.1E-1	5.6E-2
Externe par exposition aux produits (adulte)	GR 2.3E-2	8.0E-3	3.5E-3	7.4E-2	2.6E-2	9.9E-3	4.9E-2	2.0E-2	7.8E-3
Autres	3.9E-2	1.1E-2	5.0E-3	7.2E-2	1.8E-2	6.9E-3	7.7E-2	2.0E-2	1.4E-2
Total	3.1E-1	9.1E-2	2.0E-2	5.9E-1	1.4E-1	3.4E-2	6.1E-1	2.0E-1	9.2E-2
Externe par exposition aux produits (enfant)	GR 6.4E-4	2.3E-4	9.5E-5	2.4E-3	8.1E-4	2.7E-4	6.3E-4	2.3E-4	7.8E-5
Autres	1.1E-1	5.4E-2	1.5E-2	5.0E-1	1.3E-1	3.9E-2	1.7E-1	5.2E-2	1.4E-2
Total	5.9E-2	2.8E-2	6.0E-3	1.6E-1	4.5E-2	1.4E-2	1.2E-1	5.4E-2	1.4E-2
Externe par exposition aux produits (adulte)	GR 1.1E-1	5.4E-2	1.5E-2	5.0E-1	1.3E-1	3.9E-2	1.7E-1	5.2E-2	1.4E-2
Autres	1.1E-1	5.4E-2	1.5E-2	5.0E-1	1.3E-1	3.9E-2	1.7E-1	5.2E-2	1.4E-2
Total	1.1E-1	5.4E-2	1.5E-2	5.0E-1	1.3E-1	3.9E-2	1.7E-1	5.2E-2	1.4E-2
Efficace par irradiation (adulte)	GR 4.7E-3	1.7E-3	5.9E-4	1.6E-2	5.4E-3	1.8E-3	4.9E-3	1.6E-3	5.3E-4
Autres	1.1E-2	3.3E-3	9.3E-4	3.1E-2	8.2E-3	2.2E-3	1.1E-2	3.2E-3	9.0E-4
Total	7.1E-2	2.1E-2	5.7E-3	1.6E-1	4.8E-2	1.1E-2	6.0E-2	2.0E-2	5.2E-3
Efficace totale (adulte)	GR 4.8E-1	1.5E-1	4.2E-2	1.5E+0	4.2E-1	1.1E-1	5.0E-1	1.6E-1	5.0E-2
Autres	1.2E-1	3.4E-1	9.1E-2	2.9E-1	7.1E-1	1.8E-1	1.4E-1	4.0E-1	1.0E-1
Total	5.9E-1	1.7E-1	4.8E-2	1.7E+0	4.7E-1	1.2E-1	6.4E-1	2.0E-1	6.4E-2

Remarque : La fraction d'iode organique relâchée est supposée être nulle. Si les calculs avaient été réalisés en supposant que 100 % de l'iode relâché était sous forme organique, la contribution des doses à la dose aurait été :

- inchangée dans le cas de la dose externe par exposition au parastre,
- divisée par 40 dans le cas de la dose externe par exposition aux dépôts,
- multipliée par 2,5 dans le cas de la dose thyroïdienne,
- multipliée par 2 dans le cas de la dose efficace par inhalation,
- divisée par 1,5 dans le cas de la dose efficace totale.

Long term DOE/NNSA NCSP - IRSN collaboration



NCSP wants to develop and maintain modern SlideRule

- LLNL-AM3 proposal (2015)
- ORNL-AM6 proposal (2015)

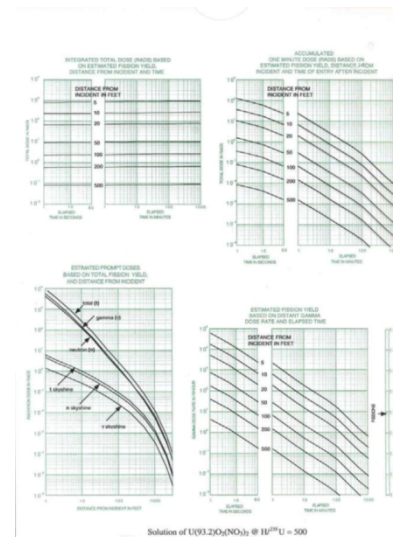
Accident analysis:		Budget Priority	
		Technical Priority	
Field-deployable emergency response methods on portable, handheld platform	Develop and maintain modern, accident analysis capability (SlideRule)		
3D accident analysis capability	Develop and deploy time-dependent multi-situation		

IRSN wants to review and improve its slide rule

- IRSN-AM5 proposal (2015)

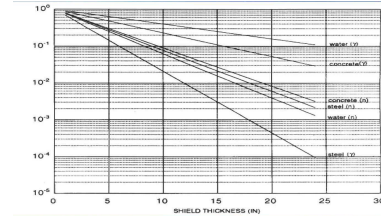
Proposal of a complete work, divided into several steps:

- **Step 1:** Redo with modern radiation transport tools, for the same configurations and assumptions, the calculations performed initially for the 1997 estimation of the doses



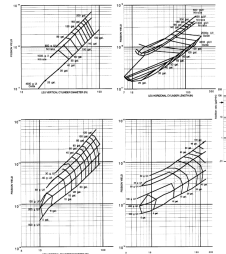
Solution of $U(93.2\text{O}_2\text{NO}_2)_2$ @ $10^{10}\text{U} = 500$

Long term DOE/NNSA NCSP - IRSN collaboration



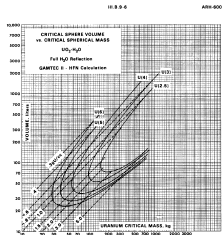
- **Step 2:** Perform additional configurations/calculations
 - New configurations (new geometry of the source, new fissile media including plutonium systems, impact of multiple layers of shielding...)
 - New flux-to-dose conversion factors (for dosimetry, radiological protection and instrumentation purposes)

- **Step 3:** Review and improve the section regarding the estimation of the number of fissions



- **Step 4:** Add other sections to the document like a section regarding actions to stop an on-going criticality accident (for example, standards with neutron poison)

- **Final step:** Based on the previous work, development of a Slide Rule "application" for a handheld device (e.g. smartphone)

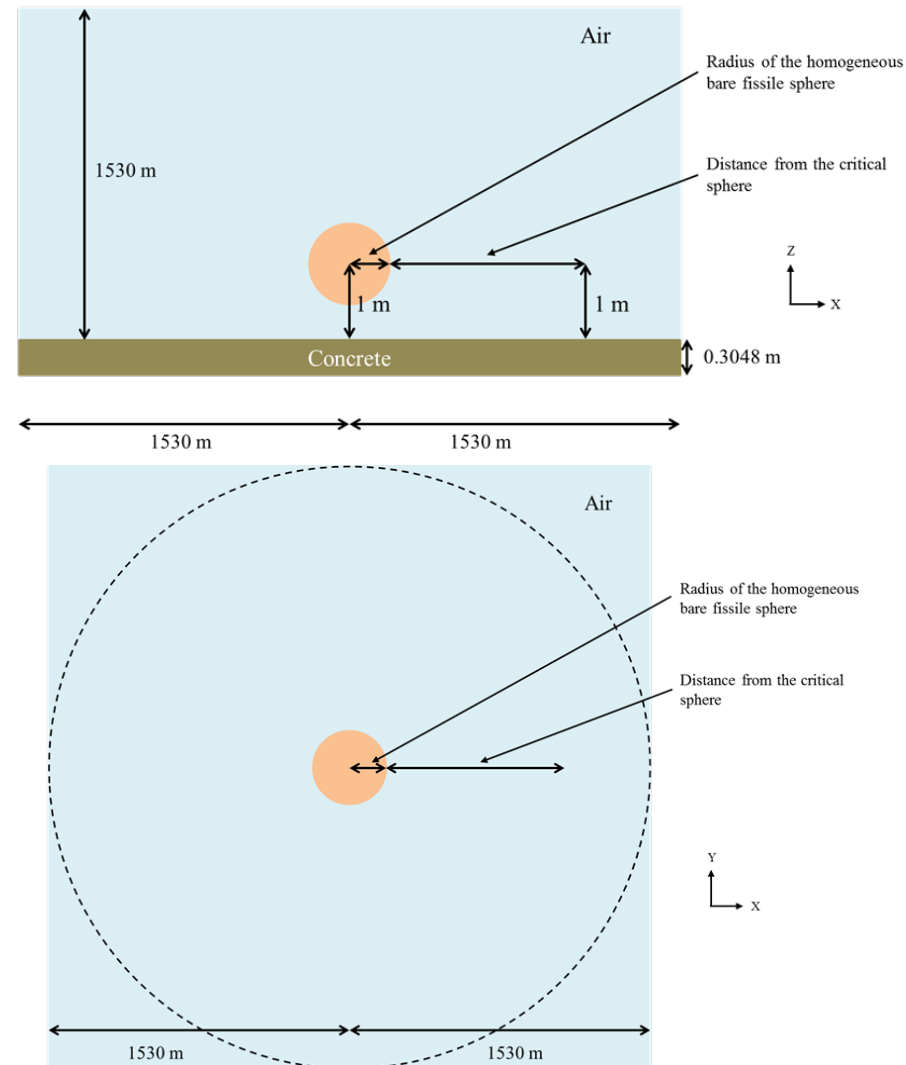


Step 1: Slide-Rule « Initial » Configuration

Geometry : One Air (sky) layer above a ~30 cm concrete layer (ground)

Source : Spherical uranium critical system – 1 meter over the ground

Dose Detection : 0.3 to 1200 meters between source and dose detection.





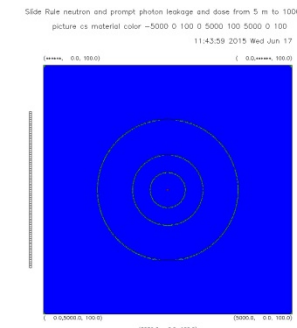
Step 1: Status and current works

- Since December 2014, IRSN has hired a contractor to work on this subject
 - Perform calculations with COG, MCNP and SCALE (and with ATTILA in the future)
- May 2015: COG installation and training (LLNL) @ IRSN
- June 2015: ATTILA training @ IRSN
- July 2015: NCSP FY2016 budget execution plan meeting @ Washington DC
- August 2015: MAVRIC training (ORNL) @ IRSN
- September 2015: 1st Slide Rule meeting @ Charlotte (ICNC)
- January 2016: Presentation of the first LLNL COG results @ LLNL
- February 2016: VTC with ORNL
- ➔ October 2016: Submission of an article to ICRS-13/RPSD-2016
 - 13th International Conference on Radiation Shielding (ICRS-13) & 19th Topical Meeting of the Radiation Protection & Shielding Division of the ANS (RPSD-2016)

COG, MCNP, MONACO Models special feature

COG : Criticality Calculation Mode

K_{eff} and dose calculation in one calculation

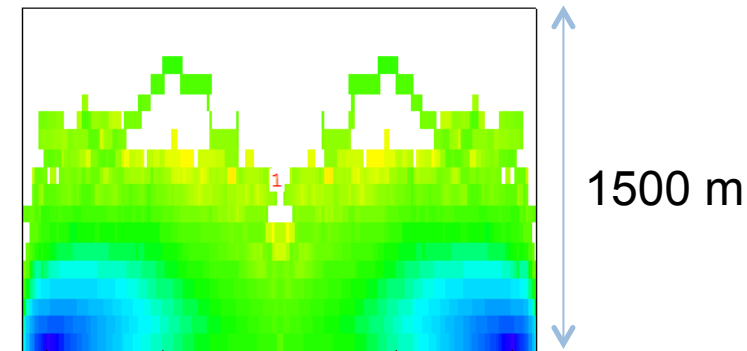


COG XY Cross-section of spherical source and toric detectors

MCNP :

First Step : KCODE (scoring fission rate)

Second Step : Fixe source calculation (ww biasing)



MCNP XZ Cross-section with weight window associated to 1000 m detection

SCALE :

First Step : XSDRNPM (scoring leakage spectrum) or KenoVI (scoring fission rate)

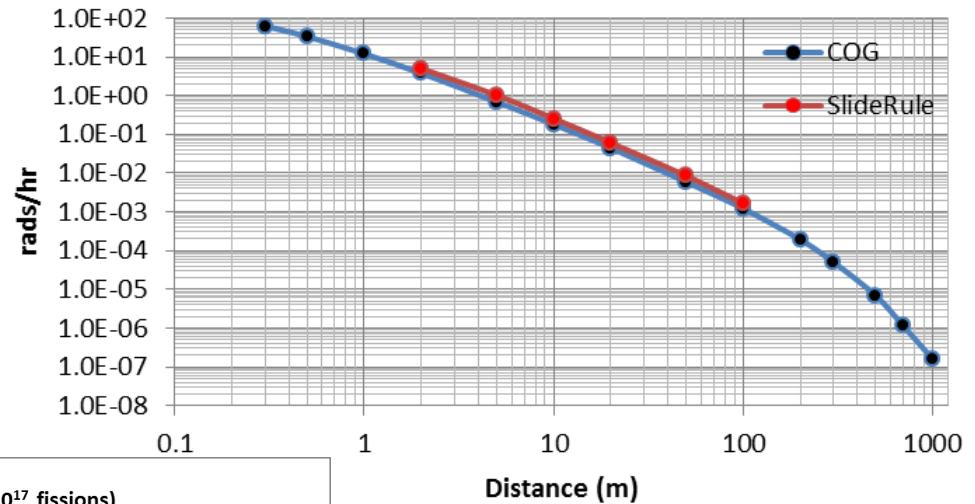
Second Step : MONACO Fixe Source calculation (Denovo map of importance).



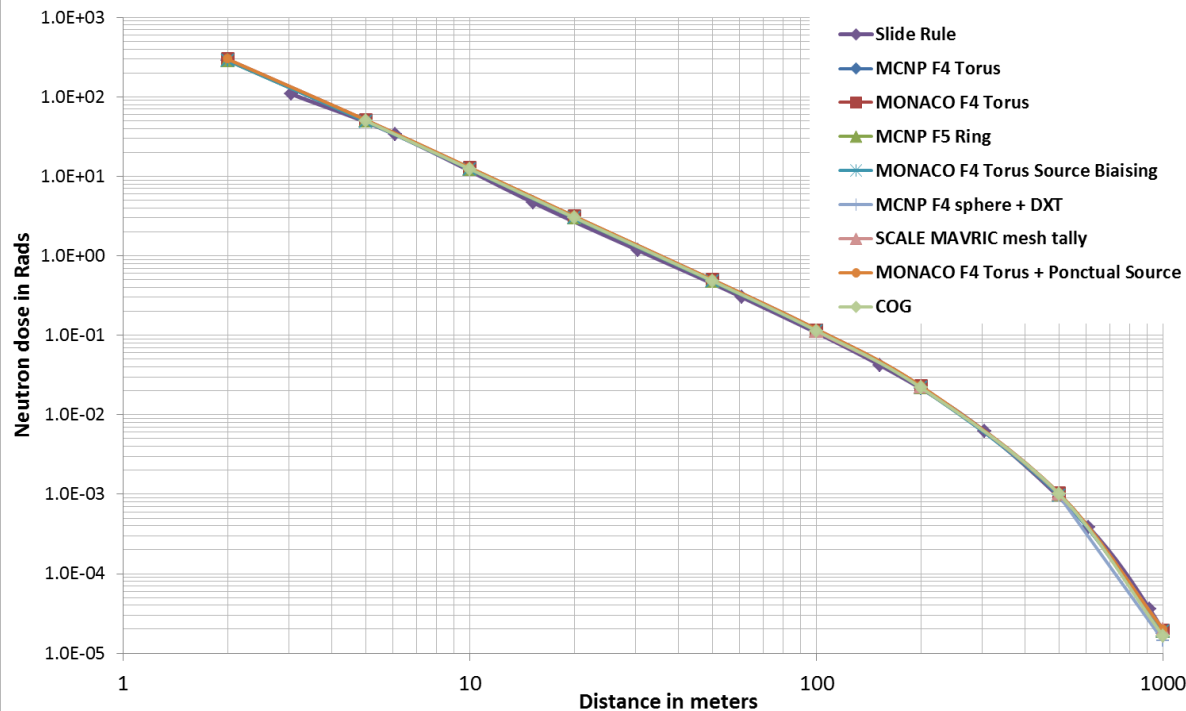
MONACO XZ Cross-section Denovo map of importance associated to 1000 m detection

Example of results IRSN / LLNL

Case 1: Aqueous Uranyl Fluoride Solution
Delayed Gamma Dose Rate at 100 min



SLIDE RULE : Neutron Dose - Uranyle fluoride (4,95 %) critical system (10^{17} fissions)



Perspectives

■ Step 1:

- ICRS-13/RPSD-2016 article
- Issue of a common report

■ Step 2:

- Discuss and validate the additional configurations

■ Other steps:

- Write a roadmap

IRSN

INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Thank you for your attention !!!

